A Combined Vibrations and Controls Course for Mechanical Engineering

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Abstract

A combined mechanical vibrations and controls course has been developed and implemented at Western Kentucky University. This 3-hour course in the senior year serves as a compromise to stand-alone courses in vibrations and controls. In addition, an integrated 1-hour laboratory section is added to support the lecture sessions. These two topics are ideal candidates for course consolidation since many of the modeling techniques are similar and the solution methods are identical.

The biggest challenge in creating a combined course such as this is in deciding on the appropriate topics to be included, while resisting the temptation to cram too much into the time period. This course is approximately 1/3 vibrations with the rest controls. This balance was chosen based on reviews of courses at other institutions as well as a review of the outcomes of other upper-division courses in the curriculum.

In order to improve the effectiveness of the course, two phases of assessment have been implemented. The first phase of the process involves overall course assessment that is common for all courses. The ME Faculty perform a collective Peer Evaluation of Course Effectiveness at the end of the semester when a class has been offered. In addition to course specific assessment, program assessment is incorporated into ME Program Outcome 1: “Mechanical Engineering graduates can formulate mathematical descriptions of physical systems to predict system response”. This program outcome is measured annually using several metrics, and this course provides one of the assignments for review.

The combined nature of the vibrations and controls course is an effective compromise to two separate courses. It provides ample opportunities for students to work on their mathematical modeling and simulation skills, and the lab provides supporting experiments to reinforce the theoretical topics. The course may serve as a model for programs with optional courses in these areas.

Introduction

This combined vibrations and controls course is offered in the seventh semester. Students have completed their Dynamics, Differential Equations, and Advanced Engineering Mathematics courses. This course provides a unique method of introducing vibrations and controls without requiring separate courses. The subject areas are complimentary, particularly when the focus of the course is primarily on modeling and prediction of system response. The controls portion benefits from the transition directly from the vibrations portion of the course. The students are very familiar with the topics, as opposed to trying to recall the information from a previous course they may have taken earlier. In fact, they are pleasantly surprised to find how the two topics can mesh together each other. In addition, the students recognize the value of their Advanced Engineering Mathematics course with additional Laplace Transforms content beyond the Differential Equations course.

This course does not sit alone in the curriculum. A Professional Component Plan[1] has been established for the curriculum, with an integral component being an experimental plan. This course and its lab strongly support this plan. In addition, a junior year instrumentation course and a senior capstone lab course[2] allow for a continuum of analysis, modeling, and measurement experiences over the students' last three semesters.

Course Description

The combined vibrations and controls course has six course outcomes, listed below:

1. Construct a mathematical model of a dynamic mechanical system
2. Use Laplace transforms to solve systems of differential equations
3. Analyze vibratory response of free and forced systems
4. Determine the transfer function for a control system
5. Determine the stability of a control system
6. Design a controller for a basic control system

These outcomes are used to support the assessment plan for the program, in particular a program outcome on mathematical modeling. These outcomes were developed concurrently with the course, and were used to guide the selection of content. The outcomes of the instrumentation course in the junior year and the senior capstone laboratory course were also considered.

The first five weeks of the course are focused on vibrations. Topics range for single degree-of-freedom (DOF) to multiple DOF systems. Some coverage of continuous systems is given, but only to a limited degree. Various traditional forced problems are reviewed, including transmission and isolation. Students work a range of problems, beginning with assignments from their sophomore dynamics text and moving into instructor provided sets.

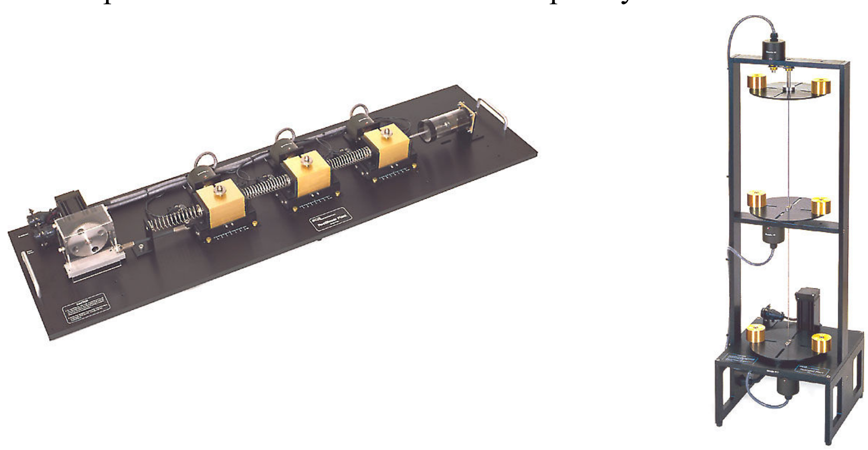
The primary focus of this section is the creation of mathematical models of systems and the prediction of response. Sessions in the laboratory allow for modeling using state-space and other matrix methods. Students conduct several analysis and measurement projects, allowing for the comparison of theoretical and actual results.

The remainder of the semester is focused on control topics. The concept of the transfer function is quickly followed by the solution and simulation of multiple problem sets. The results of these problems are used to introduce topics such as stability, steady-state error, and transient response.

Students have commented that simulation preceding the coverage of the text to be more effective for their understanding of the topics.

The root locus technique is then introduced as a tool for analysis and design. The instructor spends no time on hand sketching of the root locus, but rather uses the "rlocus" tool in Matlab to generate the loci. Students learn to use the plot to analyze and predict, and problems are assigned that force the students to use the method as an actual design tool.

No significant time is spent on frequency methods, a compromise based on time limitations. Bode plots are mentioned as a useful tool for system behavior prediction. However, extensive coverage is given to root locus design of PID systems. The laboratory section is of great use here. Four pairs (lineal and torsional) of spring/mass/damper systems from Educational Control Products are available in the lab, shown below in Figure 1. Students can work on a series of measurement and control problems on these devices, including a range of PID controller implementation tasks. Other institutions have reported success in coverage of PID topics using similar equipment[3]. Examples of experiments include system identification, particularly with respect to damping measurement. Other assignments include the prediction of system response to force inputs for comparison to Simulink models developed by the students.



Educational Control Products, ecpsystems.com

Figure 1: ECP Lineal and Torsional Test Systems

An additional mechanical vibration project involved the creation, simulation, and verification of the mathematical model for the transverse vibration of a cantilever beam, Figure 2. Students derived a model for the continuous system, and then compared these results with a 8-DOF lumped-parameter model in Matlab as well as to a finite element analysis (FEA) model. The students then devised a method of determining the mass, stiffness, and damping properties of an actual beam, and then verified their models by driving the physical system to find its harmonic response. This project was actually conducted during a senior capstone lab course, but was used to satisfy the outcomes of this specific course. Once the Department completes its move to the new Engineering Building, a wider range of experimental experiences can be supported in the controls/vibrations course.

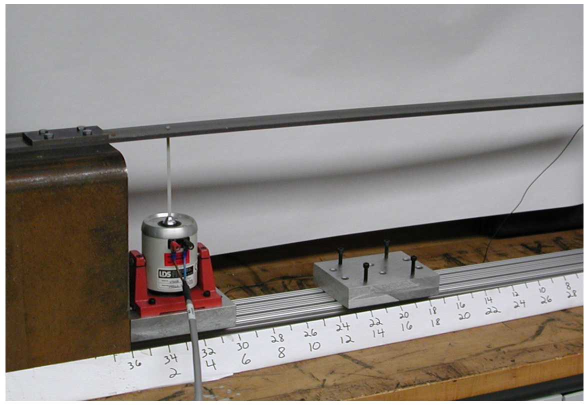


Figure 2: Transverse Beam Experiment

Changes to course content have occurred in the course, primarily in the strengthening of the PID topics. Some of these are discussed in the Lessons Learned and Conclusions section below. However, the overall concept of a combined course in the seventh semester has provided value to the students and will be continued.

Assessment Of Course

Two phases of assessment are implemented to monitor student outcomes and to improve this course. The first phase of the process involves overall course assessment that is common for all ME courses. The ME Faculty performs a collective Peer Evaluation of Course Effectiveness at the end of the semester when a class has been offered. The purpose of this structured activity is to ensure that the curriculum of each program is integrated and consistent throughout the course of study. The peer review system reviews such issues as course content, student expectations, grade distribution, and prerequisite requirements so that they are adequately understood and achieved by all program faculty members. These types of review activities are also in place at other institutions [4].

Peer Evaluation reports for each course contain a portfolio typically containing the following information: a current syllabus including student-based outcomes, copies of materials provided to students and examinations, selected examples of graded student work and the student grade distribution, as well as other material or discussion deemed important by the instructor. In addition, student self-evaluation and faculty evaluation of achieving course outcomes are presented. Faculty often use these report to present reflective criticisms of their own performance, and invite other faculty to discuss those concerns.

Student work was used to assess the six course outcomes listed earlier (shown as “Instructor” in Figure 1), and the students self-assessed their progress towards meeting the course outcomes. The results of the student and faculty assessment are shown below in Figure 3, with a score of 0 indicating no mastery and a score of 10 indicating very proficient.

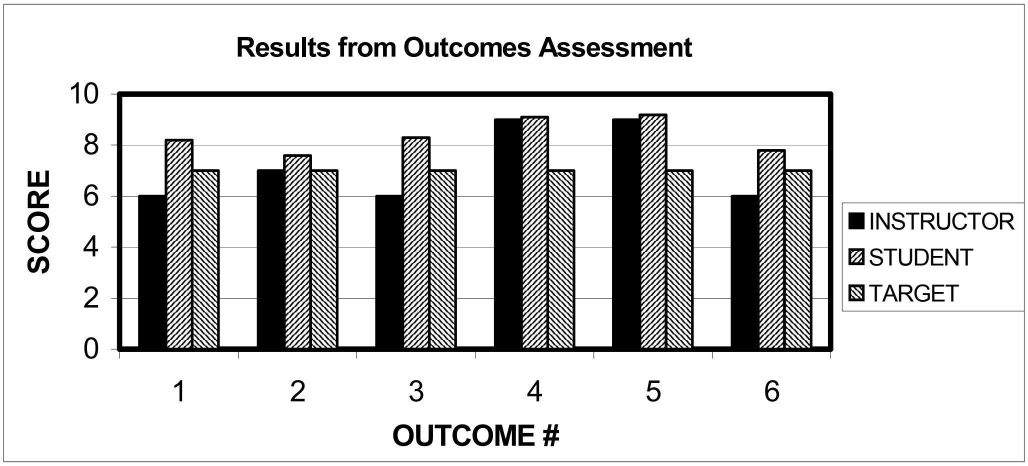


Figure 3: Course Assessment from Peer Evaluation

Student comments during the initial offering of the course indicated frustration with the use of the Matlab. Since this was a new tool for the students, time was allocated during lab meetings to cover not only the use of Matlab and Simulink but also to reinforce their use on analytical problems. Changes made to the course are discussed in the Lessons Learned and Conclusions section.

Assessment specific to this course is incorporated into ME Program Outcome 1: "Mechanical Engineering graduates can formulate mathematical descriptions of physical systems to predict system response". This program outcome is measured annually using several metrics, and this course provides multiple opportunities for generating appropriate student experiences for review.

Lessons Learned And Conclusions

The combined vibrations and controls course is proving to be an effective course in increasing the students' abilities in modeling dynamic systems. Students were able to use the tools from the course on their senior design and senior laboratory projects. A system of course and outcome review is in place, and is being used to improve the course at every offering. The course has been shown to be useful in meeting our Program Outcomes.

The use of the students' dynamics textbooks as an initial reference for the vibration component was found to improve student performance in this area. Although those books do not go into the depth needed for this course, they do provide a starting point along with worked example problems. This allows the instructor to use supplemental notes for the more advanced topics in multiple degree of freedom systems.

One of the primary improvements to the course was to focus more directly on the implementation of PID controller design, and to omit the discussion of frequency methods. There is insufficient time to cover both root locus and frequency methods, but students still have a basic understanding of controls. Root locus is the primary design tool used, and Matlab methods of creating the root locus are used exclusively. No coverage is given to drawing the loci, a compromise based again on time constraints. However, substantial time is given to understanding the plots and interpreting them for use in design.

State space representations have consistently proven to be problematic for the students, with students struggling to master the tool and to see a value in its use. An increased focus on the applications of state space models is planned for the laboratory portion of the course in the next offering.

Student use of Matlab has shown a dramatic improvement from the initial offering of the course. The Junior Design course, ME 300, in the preceding semester has a much stronger coverage of the software so that students are able to use the software at the beginning of the course. This allows the instructor to introduce simulation projects early and often to help students compare their analytical solutions in vibrations to the numerical predictions in Simulink.

Students are reminded during the course that other topics remain in both the controls and the vibrations areas. For instance, although frequency design methods for control are not covered, a brief overview of the topic is presented. The Bode plots in that chapter provide a connection to the frequency response plots generated in the vibrations section. The ME faculty are in the process of creating an optional technical elective that would be an extension of this course. The existing course is in the seventh semester, and the elective course in the eighth semester would be approximately 2/3 vibrations and 1/3 controls. Students desiring additional study in these topics for professional practice or graduate study would be encouraged to take this elective.

The approach of combining vibrations and controls into a single course could be used by programs trying to reduce the total number of hours in their curriculum. In addition, the course provides an opportunity to create a unique technical elective for programs with tracks or options in the upper division. Faculty must realize that this type of course is a compromise, and must be willing to shift pre-existing conceptions of necessary content to meet the time constraints. Topics selected for inclusion should be based on course outcomes for this and other related courses in the curriculum. The laboratory portion can be used to supplement the lecture topics to help make the connection between the two subject areas.

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